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Technical Report

FREEZE PROTECTION FOR FRESHWATER AND SANITARY PIPING UNDER OPEN PIERS

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NAVAL FACILITIES ENGINEERING COMMAND

U. S. NAVAL CIVIL ENGINEERING LABORATORY

Port Hueneme, California

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FREEZE PROTECTION FOR FRESHWATER AND SANITARY PIPING UNDER OPEN PIERS

Technical Report R-593

Y-F015-20-02-004

by

N. P. Oldson and S. L. Phelps

ABSTRACT

Pipes carrying freshwater or sewage are often exposed to severe weather conditions under piers and therefore must be protected from freezing. The Naval Civil Engineering Laboratory has studied the problems associated with freeze protection of piping systems, reviewed weather data for U.S. coastal cities having temperatures comparable to those of nearby Navy installations, conducted cold chamber tests on several freeze-protection systems, and developed freeze-protection criteria for exposed piping systems. Results of these studies indicate that freeze protection can best be obtained with conducting mineral electric heating elements insulated with polyurethane foam and protected with a covering of asphalt-impregnated felt coated with asphaltic mastic. In the colder regions, heaters, insulation, and protective covering are required; in regions of moderate winter cold only insulation and protective covering are required; and in regions having very mild winters, no insulation, protective covering, or heaters are required.

CONTENTS

INTRODUCTION

The objective of Work Unit Y-F015-20-02-004 assigned to the Naval Civil Engineering Laboratory by the Naval Facilities Engineering Command was to develop a reliable freeze protection system for piping suspended beneath open piers. Difficulties with freshwater and sanitary systems arising from their exposure to the elements under open piers are quite common. Winter temperatures in some Navy facilities on the East Coast can be as low as -30°F, and wind velocities up to 40 mph may occur simultaneously. The temperature variations are cyclic with the lowest temperatures being experienced for only a few hours on the coldest day. The pipes under the piers are sometimes subjected to the action of the waves, seawater spray, or even direct submergence in seawater at high tide.

To identify the design conditions for piping systems under open piers, a study was made of the winter weather at the representative naval stations in the continental United States. The pertinent data obtained from this study involve average winter temperatures, extreme minimum temperatures, 97.5% temperatures,* and the degree days. Materials and methods for construction, insulation, heating, and waterproofing of piping under open piers were investigated. Several concepts for freeze protection systems were conceived and a series of tests carried out in the cold chambers of the Laboratory (Appendix A). Criteria were developed for the design of freeze protection systems for piping subjected to different weather conditions.

A review of the weather conditions for representative naval stations shows that the coast may be divided into five regions (Figure 1), according to the prevailing winter weather. Tabulation of weather data and grouping of the coastal cities at which naval stations are located are presented in Appendix B.

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* The 97.5% temperature is the level which is exceeded 97.5% of the total hours in December, January, and February.

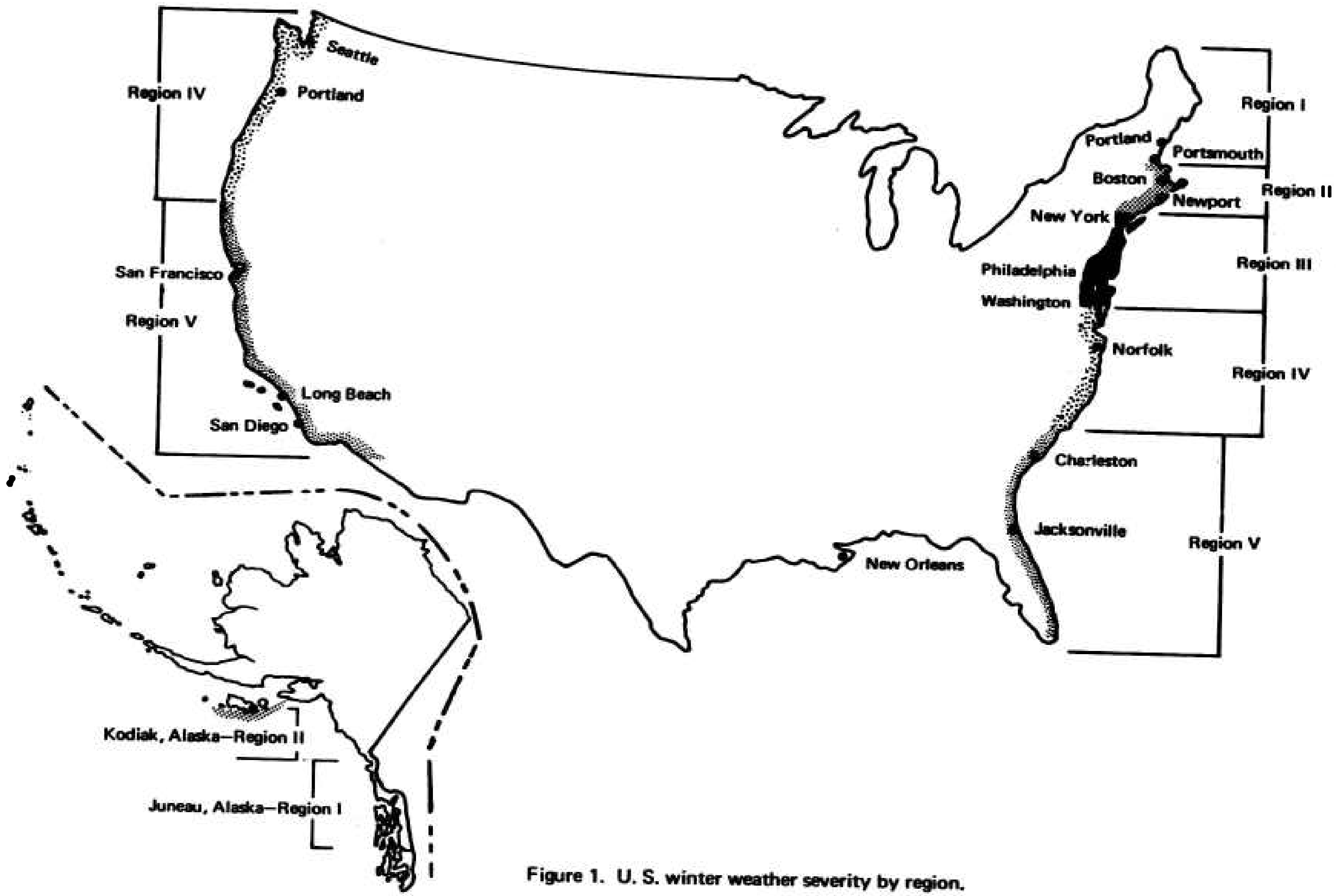

Figure 1. U. S. winter weather severity by region.

MATERIALS IN PIPING SYSTEMS

To insure effective freeze protection, the entire piping system must be considered. This includes the pipe, which is usually ferrous metal, polyvinylchloride plastic (PVC), or cement–asbestos (Transite); pipe supports; pipe insulation, which may be hair felt, fiberglass, foamed plastic (polyurethane, polystyrene), or foamed glass; the heating elements, electrical or hot fluid, which may be installed internally or externally; and the protective coverings, which may be asphalt felt, foil, fiberglass, or sheet metal.

Piping

In addition to steel pipe, polyvinylchloride plastic and cement–asbestos pipes were considered. The thermal conductivity and density of these materials are compared below.

Material	Thermal Conductivity, k Btu/(hr)(ft^2)($^\circ$F/ft)[1]	Density, ρ (lb/ft^3)
Steel	26.2 (Reference 1)	490.0
PVC	0.10 (Reference 2)	85.0
Cement–asbestos	0.43 (Reference 3)	120.0

[1] Btu's per hour per square foot per degree Fahrenheit temperature drop per foot across the pipe wall.

The thermal conductivity of PVC and cement–asbestos is two orders of magnitude lower than that of steel, but an order of magnitude higher than the conductivity of most insulating materials. In an insulated pipe system, the relatively small thickness of the pipe material adds very little to the efficiency of the system. However, the insulating effect of pipe material can significantly interfere with freeze protection afforded by external heating of the pipe. For instance, the wall thicknesses for a 3-inch nominal diameter* pipe of steel, PVC, and cement–asbestos are respectively 0.216, 0.300, and 0.530 inch. The heat loss from these three pipes would respectively amount to 95.0, 0.64, and 0.26 Btu per hour per degree Fahrenheit temperature drop across the pipe wall per foot length. If external heating elements are to be used, steel pipe should be used to insure adequate heat distribution and to prevent hot and cold spots.

* All pipes are designated by nominal pipe size in inches unless otherwise specified.

Insulation

Many kinds of materials are available for pipe insulation; properties of some of them are listed in Table 1. From the table, it may be noted that both hair felt and glass wool have high atmospheric moisture absorption and high water absorption when submerged. These materials were therefore not considered suitable for installation under open piers where the outer coverings are subjected to impact, and the pipes are subjected to submergence.

Cost information on three closed-cell insulations is contained in Table 2. The polystyrene insulation is made in nonstandard thicknesses as noted.

Table 1. Properties of Pipe Insulation

Insulation	Cell Structure	Thermal Conductivity, k Btu/(hr)(ft^2)(^{o}F/ft)*	Remarks
Hair felt	fibrous, spongy	0.023	Easily torn; high atmospheric moisture absorption; high water absorption when submerged
Glass wool	fine glass fibers	0.020	Low compressive strength; high atmospheric moisture absorption; high water absorption when submerged
Cellular glass	closed cell	0.033	High compressive strength; low atmospheric moisture absorption; protection against abrasion required; absorbs water when submerged[4]
Polyurethane foam	closed cell	0.014	Fair compressive strength; very low atmospheric moisture absorption; very low water absorption when submerged; will not withstand fire or high temperatures
Polystyrene foam	closed cell	0.021	High compressive strength; very low atmospheric moisture absorption; very low water absorption when submerged; will not withstand fire or high temperatures

* Btu's per hour per square foot per degree Fahrenheit temperature drop per foot across the pipe wall.

Table 2. Cost Comparison of Closed-Cell Pipe Insulations

(Insulation costs per foot of pipe.)

Nominal Pipe Size (in.)	Polyurethane		Cellular Glass		Polystyrene	
	Thickness (in.)	Cost ($)	Thickness (in.)	Cost ($)	Thickness (in.)	Cost ($)
3	1	1.37	1	1.39	1/	—
	1-1/2	2.29	1-1/2	1.90	1.62	1.59
	2	3.11	2	2.90	2.68	2.67
4	1	1.72	1	1.85	1/	—
	1-1/2	2.75	1-1/2	2.20	1.68	1.96
	2	3.38	2	3.50	2.56	3.05
6	1	3.15	1	2.46	1/	—
	1-1/2	3.58	1-1/2	3.12	1.81	2.93
	2	4.14	2	5.10	2.78	4.60
8	1	3.51	1	1/	1/	—
	1-1/2	4.05	1-1/2	4.20	1.78	3.90
	2	5.18	2	6.50	3.00	6.42

1/ Polystyrene normally not furnished in this thickness.

As can be seen, the costs per foot are generally similar but vary between the materials for different thicknesses and sizes. However, because of the appreciably lower thermal conductivity of polyurethane, the cost per foot for the insulating effect obtained with polyurethane is less than for the other two materials.

Protective Coverings

Protective coverings on pipes under piers reduce damage to the insulation from impact of debris and exclude moisture from the insulation. Desirable characteristics of the protective covering are water repellancy, flexibility at all temperatures, high resistance to impact damage, low cost, and ease of installation. Available protective coverings are:

1. Asphalt-impregnated asbestos building felt sealed with an asphalt mastic

2. A flexible laminated covering of asphalt-impregnated fiberglass and aluminum foil bonded and faced with bituminous polymers and sealed with a polyester film (trade name Pittwrap)
3. Preformed metal jacketing (either aluminum or galvanized steel)
4. Cement—asbestos-clad insulated pipe (sold under the trade name Temptite)
5. Polyvinylchloride-clad insulated pipe

Table 3 shows the characteristics of these protective coverings.

PIPE HEATING METHODS

In cold conditions, freeze protection may be achieved by:

1. Maintaining a flow of water sufficient to keep the temperature at 35°F
2. Heating the water by steam or electrical heat tracers within the pipe
3. Heating the pipe by steam or electrical heat tracers outside the pipe
4. Heating the pipe directly by means of its electrical resistance to a current
5. Keeping the pipe temperature above freezing by enclosing it in a heated duct or trench.

These methods are discussed below.

Flow Method

Maintaining a flow to prevent freezing within the pipe is a simple method which requires little additional equipment that is vulnerable to external damage. The flow through the pipe must maintain at least 35°F at the extreme end of the pipe under the most severe weather conditions. The flow rate will be directly proportional to the pipe length and to the difference between the average water temperature and the ambient air temperature. Water flow control may be obtained by a thermostatically controlled solenoid valve which would open when the water or pipe temperature reached about 30°F and would close at about 40°F. Manual valve control may also be used. For conditions less severe than the design conditions, cycling of the flow control system will reduce the overall flow rate.

Table 3. Comparison of Protective Coverings

Protective Covering	Water Repellancy	Flexibility	Resistance to Impact	Installation	Cost Per Foot for 3-Inch IPS ($)	Remarks
Asphalt-impregnated felt with asphalt coating	excellent; joints must be properly covered with asphalt coating	not flexible at low temperatures	good at temperatures above 40°F; fair from 40°F to 20°F; tends to crack at temperatures below 20°F	relatively easy; two layers are required	0.10 to 0.15	two layers of felt are required
Pittwrap laminated covering	excellent; joints must be sealed properly	not flexible at low temperatures	similar to that of asphalt paper, but tougher at all temperatures	easy	0.45	seals can be made with heat only
Preformed metal jackets	excellent; joints must be sealed	equally flexible at all temperatures	very good at all temperatures	easy except for sealing joints	0.30 1/	joints are difficult to maintain completely waterproof
Cement–asbestos clad	excellent	rigid	good at all temperatures	difficult because sections heavy; support must be adequate	2/	pipe, insulation, and protective covering come as a unit
PVC clad	excellent	semirigid	good at all temperatures	joints difficult because pipe, insulation, and covering are in a unit	2/	pipe, insulation, protective covering, and heating element come as a unit

1/ Galvanized steel.

2/ Cost comparisons for coverings of cement–asbestos-clad pipes and PVC-clad pipes are not meaningful as pipes, insulation, and coverings come as units. The heating element also can be included with the PVC-clad pipe.

Advantages of this system are that the system is simple to install, and its cost is low. Only a thermostat, a solenoid valve, and the necessary wiring are required. Disadvantages of this system are that the solenoid valve must be kept clear and protected from freezing so that full flow is obtained when it is open, and the flow from water pipes is discharged to the sea and lost. Where large heat losses are experienced by the piping system, the loss of freshwater may be unacceptably high.

Internal Heat Tracers

Steam. Heating the water by heat tracers within the pipe is much more complicated than the method just described. The use of an internal steam tracer in a piping system is attractive because steam is usually available at the piers. The cost of installing a steam tracer is relatively low—$0.20 per foot for nominal 1/4-inch copper tubing.

Problems which may be encountered with this system are

1. Special fittings would be required to permit entry of the steam trace into the pipes and to bypass valves and fittings. The tracer would need to have breakable joints wherever pipe flanges are installed so that repairs or replacement of pipe sections can be accomplished.

2. Good drainage of condensate would be necessary for proper operation of the system. Where long lines along piers are involved, maintaining a slope in the tracer for condensate drainage may be difficult.

3. Provision has to be made for differences in expansion between the pipe and the tracer.

4. Steam traps and condensate discharge lines have to be protected from freezing.

5. Because steam will be warmer than 212°F, the water in the pipe may be overheated at the inlet end when the outlet is just above freezing. Objectionably high temperatures in freshwater lines may result with steam tracers.

Although the cost of the steam tracer tube will be relatively low, the special fittings required and the installation of the system will make the overall costs moderately high.

Electrical. The installation of internal electrical tracers (copper-sheathed, mineral-insulated resistance cable) is similar to that of the internal steam tracer. The electrical system eliminates the problems with condensate drainage, traps, or discharge protection inherent in the steam tracer system, and better

temperature control would be obtained. However, the need for special fittings is common to both systems. Bends would be difficult to make with the electrical tracer, and breakable joints would not be permitted. Pipes must be full of water when the heating element is energized.

The cost of the mineral-insulated element is relatively high (about $0.70 per foot) and with special fittings, connectors and installation will make the system exceptionally high.

External Heat Tracers

Steam. Heating the pipe by heat tracers outside the pipe eliminates the problems of entry into the pipe and of bypassing valves and fittings which are inherent of the internal tracer systems. Use of external steam tracers presents the same problems of drainage of condensate and prevention of freezing of traps and discharge lines that internal steam tracers have.

Additional problems with the external steam lines are: (1) obtaining good heat transfer from the steam tracer to the pipe requires installation with a special heat conducting cement; (2) the insulation on the pipe must be formed to fit around the steam tracer; and (3) any leakage from the steam tracer will saturate water absorbent insulation or will collect within the protective covering and cause difficulties.

Control of the system will be similar to that for the internal tracer system.

The pressure-reducing station, tracer tube, heat-conducting cement, fittings at flanges, and condensate traps will put the cost of material at about $0.60 per foot.

Electrical. External electrical tracers or heaters are available as cables, strips, and tapes. These have the installation advantages of the external steam tracers without the problems of condensate disposal and possible water leakage. Cable type heaters will require heat conducting cement like the steam tracer whereas tapes or strips lie flat against the pipe wall and when properly taped to the pipe do not require cement to obtain good heat transfer between the heater and the pipe.

Some available heating elements are mineral-insulated cable (MIC), silicone-rubber-protected heating elements, rubber-protected-mesh heating elements, and conductive mineral film elements. Figure 2 shows some of the details of these elements. The properties of these units are described below.

Mineral insulated cable consists of a resistance wire heating element surrounded by a powdered mineral insulator enclosed in a copper sheath. This unit is waterproof and is made with many sizes of resistance wire so that varied lengths and heating rates are possible.

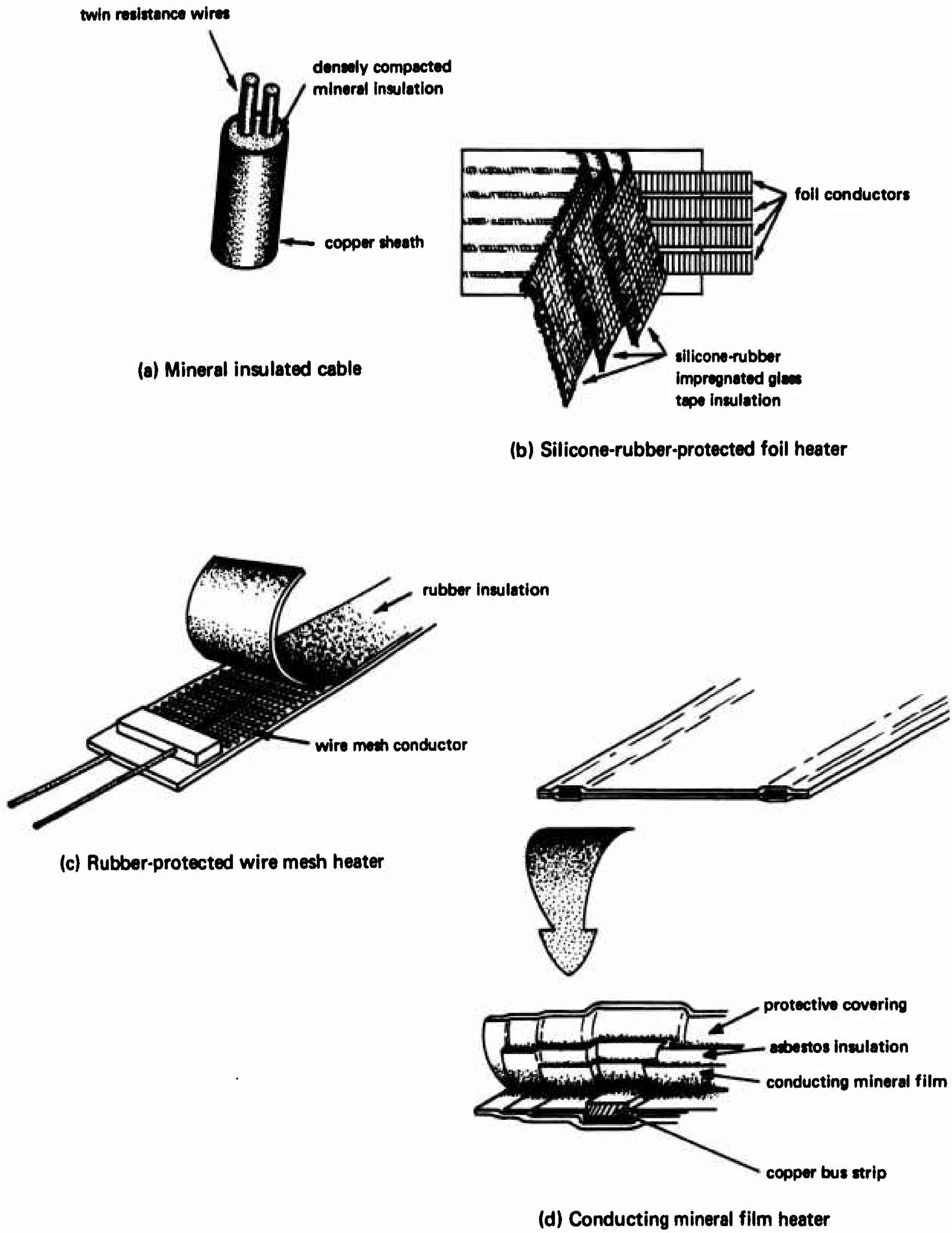

Figure 2. Electric heating cables.

The end fittings are difficult to make up and generally the units should be ordered to specific lengths. Care must be taken when the elements cross pipe flanges to prevent damage to the element. The units are not easily removed and are subject to kinking and breaking if improperly handled. To obtain good contact between the round element and the pipe surface a special heat conducting cement should be applied.

Silicone-rubber-protected foil elements have the trade name Hot Foil. Hot Foil type GW is a heating element in an extruded silicone rubber sheath which is waterproof and can withstand temperatures up to 200°F. Although it is waterproofed, this type of element must not be used internally. It is flexible and easily installed. Units up to 70 feet in length can be made with heat rates of approximately 6, 12, 30, and 50 watts per foot. The units are made up to a specific size and elements are readily attached to pipe with tape. For long lengths of pipe, multiple units must be installed. Pipe flanges, except at the end of an element, are difficult to cross without exposing the element to possible damage.

Rubber-protected-mesh heating elements are made under the trade name Electro-mesh. The heating element is custom made to specification. By selecting wire of the proper resistance, units of almost any length and heat rate can be made. If the element is damaged, it cannot be repaired in the field. Electro-mesh is wide, thin, and flexible. Good heat transfer can be obtained without special heat transfer cement. It is in the medium to high price bracket.

Electro-wrap is a thin heater element that is rated at 6-1/2 or 24 watts per lineal foot regardless of length. The element is only about 0.025 inch thick, and is made up of a protective covering of Teflon or Scotchpak, asbestos insulation, the electrical conducting film, and two copper bus strips. The element may be obtained with an adhesive backing if desired. Two copper bus strips are on each side of the element with the conducting film between. It is possible to cut the elements to any length, and to connect elements together in series in the field. A total length of about 300 feet can be connected in series. Electro-wrap is moderately high priced, but the great advantage of this element over others is that it can be cut, spliced, or repaired in the field. The approximate location of a break in an element, should it occur, can be determined by an ammeter reading.

Table 4 is a comparison of the four types of external electric heat tracers. As shown, the most economical method of heating is with the mineral insulated cable. Consideration must be given, however, to the problems in installing the MIC heaters as compared to the more easily installed and repaired but more expensive Electro-wrap tape. The other more expensive tapes have no apparent advantage over the MIC cable.

Table 4. Comparison of Electric Tracers

Type or Trade Name	Watts Per Foot	Maximum Length[1] (ft)	Cement Required	Cost ($/ft)	Field Assembly	Comments
Mineral insulated cable (MIC)	wide range	wide range	yes	1.00	difficult	Insulation must clear cable when cemented on pipe. Flanges can be bypassed with nonheating MIC, or the element can be formed around the flange. Joints in the cable are difficult to make.
Electro-wrap conducting mineral film tape with Scotchpak protective covering	6.5	300	no	1.90	easy	Flanges can be bypassed with nylon insulated wire or by nonheating MIC. Tape is easily cut and connections are easily made in field.
Electro-wrap conducting mineral film tape with Teflon protective covering	24 or 6.5	100 300	no	2.75	easy	
Electro-mesh rubber-covered heating element	12 to 700	100	no	3.40	elements made to specified lengths	Flanges can be bypassed. Fitting elements in the field is not feasible.
Hot Foil silicone rubber covered foil element	4 to 120	70	no	3.80	elements made to specified lengths	Flanges can be bypassed. Fitting elements in the field is not feasible.

[1] Length for single circuit.

Control of all the electrical heating elements can be obtained with a thermostat set at 35^{o}-$40^{o}F$ actuating the heater elements. The thermostat bulb should be attached adjacent to or on the heat tracer for better control of temperature.

Direct Resistance Heating

Direct resistance heating utilizing the pipe as a conductor generates heat from the resistance of the pipe to the current flow. In order to use direct resistance heating, good electrical contact must be obtained, all electrical grounds in the system must be removed, and low voltage (40 to 60 volts) should be used. Problems of electrically isolating the pipes under piers in addition to the safety hazard in having the pipes at a potential of 40 to 60 volts (with higher voltages possible if a short circuit in a transformer occurs) are increased with the possibility of the pipes actually being submerged. For these reasons, the use of direct resistance heating was not considered further for this application.

Heated Enclosures

Heated enclosures may be used for piping systems to maintain the pipe temperatures above $32^{o}F$. In enclosures which also contain steam pipes, the heat lost from insulated steam pipes is usually not adequate to keep the temperature in the enclosure above freezing, and a separate heating system either for the enclosure or for the water pipes must be provided.

DESIGN CRITERIA

General Considerations

Freezing of water within a pipe may be expected whenever the ambient air temperature goes below $32^{o}F$. If the water temperature is reduced to $32^{o}F$, freezing will be initiated at the pipe wall. The rate of ice formation will be dependent on the heat losses from the pipe and the mass and latent heat of fusion of the water in the pipe. If a solid plug of ice is permitted to form, high stresses may be produced in the piping system; however, if freezing is limited to one half the volume of the pipe the unfrozen central core would relieve the pressure and high stresses in the piping would be avoided.

The formation of ice on the outside of the pipe is not generally a problem as the seawater splashing up on the pipe must be rapidly chilled well below 28°F in order for the water to freeze on the surface. For an insulated pipe, the low mass of the insulation and low heat transfer rate through the insulation limits the rapid chilling of the seawater. Ice formation on the outside of the pipe is slow and excessive buildup seldom occurs.

Factors affecting the freezing of piping systems are (1) the heat transfer characteristics of the system, (2) the heat stored within the system and the amount of latent heat in the ice permitted to form in the system, and (3) the characteristics of heaters if they are used. A short discussion on each of these factors follows:

Heat Transfer. Thermal conductivity of the system is affected by:

1. The heat transfer coefficient at the interface between the outer surface and the air
2. The thermal conductivities of the protective covering and insulation, if used, and the pipe wall itself
3. The heat transfer coefficient at the interface between the inner surface and the water
4. The thermal conductivity of ice, if it has formed

Stored Heat. The heat stored within the system is dependent on the initial temperature, the mass, and the specific heats of the components of the system. Of these three variables, only the mass of the system is within the control of the designer. However, it would be very uneconomical to increase the entire system size simply to provide a large heat storage. The heat available from the latent heat of fusion of ice depends on how much of the water contained in the system will be allowed to freeze.

Heater Characteristics. If heaters are used, they are controlled by a thermostat mounted near the heater on the outside of the pipe or suspended within the water on the inside of the pipe. The thermostats operate on an on-off cycle over a fairly wide temperature span (6°-10°F). It is to be expected that with this type of control, the heaters will be activated for about 50% to 60% of the time. If heaters are selected to operate on this on-off cycle, it may be expected that an output about 20% higher can be met by the heaters being activated 60% to 75% of the time. Adequate temperature control is not obtained if longer operating cycles are attempted.

Representative values of the heat transfer coefficients and the thermal conductivities of concern to the piping systems are discussed in Appendix C.

Design Weather Conditions

For the design of freeze prevention systems, it was assumed that there was no flow through the pipes. It was also assumed that the duration of the most severe weather would be equivalent to 6-3/4 days at the 97.5% temperature* plus 2-1/4 days at the average temperature between the 97.5% temperature and the extreme minimum temperature. In Regions I and II where the average January temperatures are 24°F and 29°F respectively, it is expected that the diurnal variations in temperature will be generally below 32°F so that little or no warming of the pipes could be expected from the ambient air. Piping systems therefore must be heated in these regions to maintain the pipe temperatures at 32°F for ambient air temperature at the 97.5% value for an indefinite period. Also, the heat losses from the piping systems must be such that if the average temperature between the 97.5% value and the extreme minimum is maintained continuously for 54 hours, not more than 50% of the water contained within the pipe will be frozen.

In Regions III and IV, however, it is expected that the periods of low ambient temperatures will be shorter and the average conditions with diurnal variations will be above 32°F so that warming of the piping systems from ambient conditions can be expected. In these regions, the assumption that insulation alone is adequate to prevent freezing is supported by References 6 and 7. Heat losses, therefore, from the piping systems must be such that if the 97.5% temperature is maintained continuously for 6-3/4 days (162 hours) and in addition, the average of the 97.5% value and the extreme minimum is maintained for 2-1/4 additional days (216 hours total), the water contained within the pipe will not be more than 50% frozen.

In Region V, the 97.5% value is 32°F and below freezing weather is not expected to be of sufficient duration to cause complete freezing of the water within the pipes.

Heaters Required for Protection

In Regions I and II, heaters are required in addition to insulation, and an economical balance between the two must be maintained. The polyurethane foam material was considered for insulation of the pipe. Figure 3 plots the heat losses per hour per foot of pipe per degree Fahrenheit temperature drop across the pipe wall for various pipe sizes and various thicknesses of polyurethane insulation ($k = 0.014$ Btu/(hr)(ft^2)(°F/ft)). This information

* The 97.5% temperature is the level which is exceeded 97.5% of the total hours in December, January, and February.

is applicable to all five regions and may also be used for other kinds of insulation if the thicknesses are adjusted to provide heat transfer comparable to the polyurethane. Tables 5 and 6 present data on the expected heat losses from pipes in Regions I and II, respectively, when subjected to the design weather conditions indicated in Appendix A for these regions.

A comparison between sections **a** and **b** of Tables 5 and 6 shows that heaters adequate for the 97.5% conditions **a** when operating 50% of the time, will satisfy the extreme conditions **b** when operating 75% of the time. Also, with the heaters merely able to meet the 97.5% conditions, less than 50% of the volume will freeze after 54 hours of the extreme condition.

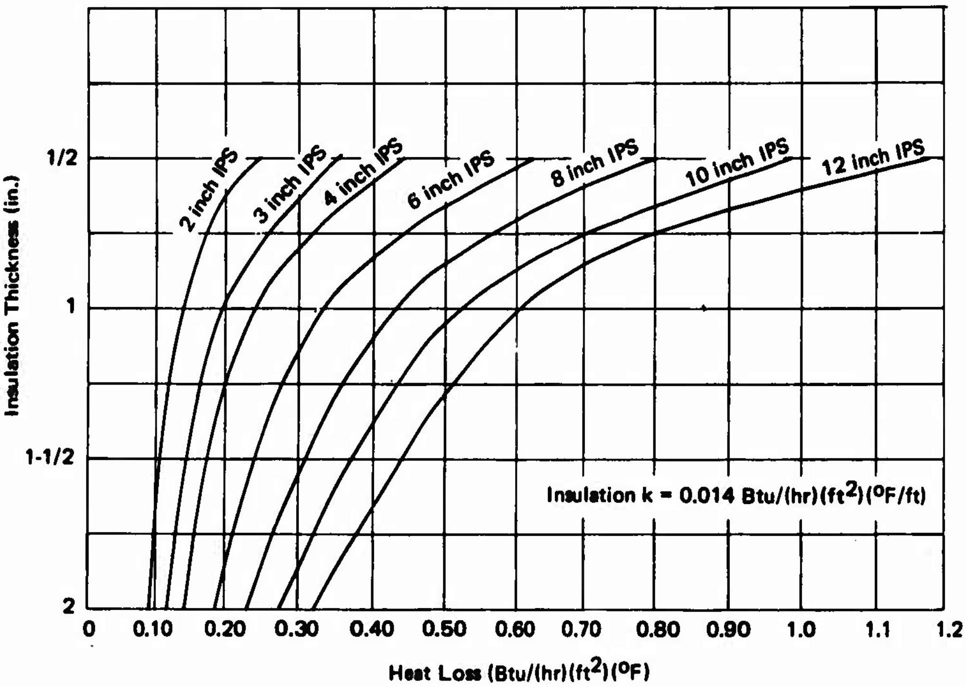

Figure 3. Heat losses for various pipe sizes.

Heaters Not Required for Protection

In Regions III and IV, insulation on the pipes will keep them from freezing when the pipes are subjected to the design weather conditions indicated in Appendix A for these regions. Tables 7 and 8 show heat losses per hour expected for pipes in Regions III and IV respectively, for a number of pipe sizes and insulation thicknesses, and the cumulative losses for the expected durations of the cold periods. Tables 9 and 10 compare the total heat lost for the 9-day cold period with the losses required to freeze the water within the pipe for these regions, respectively. The boldface values in these tables indicate the heat loss levels for insulation thicknesses that will afford adequate protection for piping in these regions.

Table 5. Heat Losses of Pipes in Region I

Nominal Pipe Size (in.)	Heat Losses and Power Deficits[1] for Insulation Thickness of—							
	1/2 Inch		1 Inch		1-1/2 Inches		2 Inches	
	Btu/(hr)(ft)	Watts	Btu/(hr)(ft)	Watts	Btu/(hr)(ft)	Watts	Btu/(hr)(ft)	Watts
(a) Temperature Difference of 32°F[2]								
2	8.0	2.4	4.6	1.4	3.4	1.0	2.9	0.9
3	11.3	3.3	6.4	1.9	4.6	1.4	3.7	1.1
4	14.1	4.2	7.7	2.3	5.6	1.7	4.5	1.3
6	20.2	6.0	10.8	3.2	7.6	2.2	6.0	1.8
8	25.8	7.6	13.6	4.0	9.5	2.8	7.4	2.2
10	31.8	9.4	16.7	4.9	11.6	3.4	9.0	2.7
12	37.8	11.2	19.6	5.8	13.2	3.9	10.3	3.0
(b) Temperature Difference of 47°F[3]								
2	11.8	3.5	6.8	2.0	5.1	1.5	4.2	1.2
3	16.6	4.9	9.2	2.7	6.7	2.0	5.4	1.6
4	20.6	6.1	11.3	3.3	8.2	2.4	6.5	1.9
6	29.6	8.7	15.8	4.7	11.2	3.3	8.8	2.6
8	38.0	11.2	19.9	5.9	13.9	4.1	10.9	3.2
10	46.8	13.8	24.4	7.2	16.9	5.0	13.1	3.9
12	55.5	16.4	28.7	8.5	19.3	5.7	15.1	4.5

1/ Power required to make up heat losses.

2/ Pipe wall temperature 32°F, air temperature 0°F.

3/ Pipe wall temperature 32°F, air temperature -15°F.

Table 6. Heat Losses of Pipes in Region II

Nominal Pipe Size (in.)	Heat Losses and Power Deficits[1] for Insulation Thickness of—							
	1/2 Inch		1 Inch		1-1/2 Inches		2 Inches	
	Btu/(hr)(ft)	Watts	Btu/(hr)(ft)	Watts	Btu/(hr)(ft)	Watts	Btu/(hr)(ft)	Watts
(a) Temperature Difference of 22°F[2]								
2	5.5	1.6	3.2	0.95	2.4	0.7	2.0	0.6
3	7.8	2.3	4.3	1.3	3.1	0.9	2.5	0.75
4	9.7	2.9	5.3	1.6	3.8	1.1	3.0	0.9
6	13.9	4.1	7.2	2.1	5.0	1.5	4.1	1.2
8	17.8	5.2	9.4	2.8	6.5	1.9	5.1	1.5
10	22.0	6.5	11.5	3.4	7.9	2.3	6.1	1.8
12	26.0	7.7	13.4	3.9	9.1	2.7	7.1	2.1
(b) Temperature Difference of 34°F[3]								
2	8.5	2.5	4.9	1.4	3.7	1.1	3.0	0.9
3	12.0	3.5	6.7	2.0	4.9	1.4	3.9	1.2
4	14.9	4.4	8.2	2.4	5.9	1.7	4.7	1.4
6	21.4	6.3	11.1	3.3	8.1	2.4	6.3	1.9
8	27.4	8.1	14.5	4.3	10.1	3.0	7.9	2.3
10	33.9	10.0	17.7	5.2	12.3	3.6	9.5	2.8
12	40.0	11.8	20.8	6.1	14.0	4.1	11.0	3.2

[1] Power required to make up heat losses.

[2] Pipe wall temperature 32°F, air temperature 10°F.

[3] Pipe wall temperature 32°F, air temperature -2°F.

In Region V, mild weather prevails, and no insulation is considered necessary. In the event that below freezing temperatures prevail for more than 24 hours, flow through the pipes for 2 hours at twice the flow rate given in Table 11 will clear the pipes of any ice which may have formed. Where pipes are in use, of course, this requirement is not necessary.

Table 7. Heat Losses of Pipes in Region III

Nominal Pipe Size (in.)	Heat Losses Per Foot of Pipe at Temperature Difference of 17°F[1] for Insulation Thickness of—							
	1/2 Inch		1 Inch		1-1/2 Inches		2 Inches	
	Btu/(hr)(ft)	Btu/(162 hr)(ft)	Btu/(hr)(ft)	Btu/(162 hr)(ft)	Btu/(hr)(ft)	Btu/(162 hr)(ft)	Btu/(hr)(ft)	Btu/(162 hr)(ft)
2	4.3	697	2.5	405	1.8	292	1.5	243
3	6.0	972	3.3	535	2.4	389	2.0	324
4	7.5	1,215	4.1	664	3.0	486	2.3	373
6	10.7	1,733	5.7	923	4.0	648	3.2	518
8	13.7	2,219	7.2	1,166	5.1	826	3.9	632
10	17.0	2,754	8.9	1,442	6.1	988	4.7	761
12	20.0	3,240	10.4	1,685	7.0	1,134	5.5	891

Nominal Pipe Size (in.)	Heat Losses Per Foot of Pipe at Temperature Difference of 24°F[2] for Insulation Thickness of—							
	1/2 Inch		1 Inch		1-1/2 Inches		2 Inches	
	Btu/(hr)(ft)	Btu/(54 hr)(ft)	Btu/(hr)(ft)	Btu/(54 hr)(ft)	Btu/(hr)(ft)	Btu/(54 hr)(ft)	Btu/(hr)(ft)	Btu/(54 hr)(ft)
2	6.0	324	3.5	189	2.6	140	2.1	113
3	8.5	459	4.7	254	3.4	184	2.8	151
4	10.5	567	5.8	313	4.2	227	3.3	178
6	15.1	815	8.1	437	5.7	308	4.5	243
8	19.4	1,048	10.2	551	7.1	383	5.5	297
10	23.9	1,291	12.5	675	8.6	464	6.7	362
12	28.3	1,528	14.7	794	9.9	535	7.7	416

1/ Pipe wall temperature 32°F, air temperature 15°F.
2/ Pipe wall temperature 32°F, air temperature 8°F.

Table 8. Heat Losses of Pipes in Region IV

Nominal Pipe Size (in.)	Heat Losses Per Foot of Pipe at Temperature Difference of 8°F 1/ for Insulation Thickness of—							
	1/2 Inch		1 Inch		1-1/2 Inches		2 Inches	
	Btu/(hr)(ft)	Btu/(162 hr)(ft)	Btu/(hr)(ft)	Btu/(162 hr)(ft)	Btu/(hr)(ft)	Btu/(162 hr)(ft)	Btu/(hr)(ft)	Btu/(162 hr)(ft)
2	2.0	324	1.1	178	0.9	146	0.7	113
3	2.8	454	1.6	259	1.1	178	0.9	146
4	3.5	567	1.9	308	1.4	227	1.1	178
6	5.0	810	2.7	437	1.9	308	1.5	243
8	6.5	1,053	3.4	551	2.4	389	1.8	292
10	8.0	1,296	4.2	680	2.9	470	2.2	356
12	9.4	1,523	4.9	794	3.3	535	2.6	421
Nominal Pipe Size (in.)	Heat Losses Per Foot of Pipe at Temperature Difference of 19°F 2/ for Insulation Thickness of—							
	1/2 Inch		1 Inch		1-1/2 Inches		2 Inches	
	Btu/(hr)(ft)	Btu/(54 hr)(ft)	Btu/(hr)(ft)	Btu/54 hr)(ft)	Btu/(hr)(ft)	Btu/(54 hr)(ft)	Btu/(hr)(ft)	Btu/(54 hr)(ft)
2	4.8	259	2.8	151	2.1	113	1.7	92
3	6.7	362	3.8	205	2.7	146	2.2	119
4	8.3	448	4.6	248	3.3	178	2.6	140
6	12.1	653	6.4	346	4.5	243	3.5	189
8	15.5	837	8.1	437	5.6	302	4.4	286
10	19.1	1,031	9.9	535	6.9	373	5.3	286
12	22.6	1,220	11.6	626	7.8	421	6.1	329

1/ Pipe wall temperature 32°F, air temperature 24°F.
2/ Pipe wall temperature 32°F, air temperature 13°F.

Table 9. Comparison of Heat Losses Required to Freeze Water in Pipes and Total Heat Losses in Region III for 9-Day Period[1]

(Boldface values indicate heat losses for insulation thicknesses that afford adequate freeze protection)

Nominal Pipe Size (in.)	Heat Losses Required to Freeze Solid (Btu/ft)	Heat Losses (Btu/ft) for Insulation Thickness of—				Remarks
		1/2 Inch	1 Inch	1-1/2 Inches	2 Inches	
2	210	1,020	594	432	350	Will be frozen solid
3	460	1,431	789	573	475	Will be frozen solid
4	800	1,782	977	713	551	2-inch insulation is of questionable value; 69% of water will be frozen
6	1,800	2,548	1,360	**956**	**761**	53% will be frozen with 1-1/2-inch insulation
8	3,180	3,267	**1,717**	**1,209**	**929**	54% will be frozen with 1-inch insulation
10	4,900	4,045	**2,117**	**1,452**	**1,123**	43% will be frozen with 1-inch insulation
12	7,150	4,758	**2,479**	**1,669**	**1,307**	35% will be frozen with 1-inch insulation

1/ 6-3/4 days at 15°F and 2-1/4 days at 8°F.

Table 10. Comparison of Heat Losses Required to Freeze Water in Pipes and Total Heat Losses in Region IV for 9-Day Period[1]

(Boldface values indicate heat losses for insulation thicknesses that afford adequate freeze protection)

Nominal Pipe Size (in.)	Heat Losses Required to Freeze Solid (Btu/ft)	Heat Losses (Btu/ft) for Insulation Thickness of—				Remarks
		1/2 Inch	1 Inch	1-1/2 Inches	2 Inches	
2	210	583	329	259	205	Will freeze solid
3	460	816	464	324	**265**	58% will freeze with 2-inch insulation
4	800	1,015	556	**405**	**318**	51% will freeze with 1-1/2-inch insulation
6	1,800	1,463	**783**	**551**	**432**	44% will freeze with 1-inch insulation
8	3,180	1,890	**988**	**691**	**530**	31% will freeze with 1-inch insulation
10	4,900	**2,327**	**1,215**	**843**	**642**	47% will freeze with 1/2-inch insulation
12	7,150	**2,743**	**1,420**	**956**	**750**	38% will freeze with 1/2-inch insulation

1/ 6-3/4 days at 24°F and 2-1/4 days at 13°F.

Table 11. Freezing Times and Protective Water Flow Rates and Volumes for Pipes in Region V

(Uninsulated, 600-foot-long pipes)

Nominal Pipe Size (in.)	Heat Losses Required to Freeze 50% (Btu/ft)	Time Required to Freeze 50% at Air Temperature of 25^{o}F (hr)	Percent Frozen in 10 Hours of 25^{o}F Air Temperature	Flow of 50^{o}F Water Required to Prevent Freezing (gpm)	Volume of 50^{o}F Water Required to Free Pipe of Ice After 10 Hours of 25^{o}F Air Temperature (gal)
2	105	11	46	3.5	450
3	230	16	30	5.0	630
4	400	22	23	6.8	830
6	900	33	15	10.0	1,240
8	1,590	43	12	13.0	1,640
10	2,450	53	9	16.3	2,050
12	3,575	66	7.6	19.6	2,440

SUMMARY

In Regions I and II, pipes under piers must be protected by heating elements in addition to insulation and protective covering. The most economical arrangements are obtained with polyurethane insulation, conductive mineral film electrical heating elements, and asphalt-impregnated felt overlaid with asphalt mastic protective covering. The recommended combinations are shown in Table 12.

Table 12. Recommended Combinations of Heating and Insulation for Pipe Protection in Regions I and II

Nominal Pipe Size (in.)	Region I		Region II	
	Insulation Thickness (in.)	Heating (w/ft)	Insulation Thickness (in.)	Heating (w/ft)
2	1/2	6.5	1/2	6.5
3	1/2	6.5	1/2	6.5
4	1	6.5	1	6.5
6	1	6.5	1	6.5
8	1-1/2	6.5	1	6.5
10	1	24.0	1-1/2	6.5
12	1	24.0	1-1/2	6.5

In Regions III and IV, the most economical method of protection is obtained by insulating the pipes and flushing water through the pipes once a day when unusually low ambient temperatures occur. The recommended combinations are shown in Table 13.

In Region V, pipes under piers need not be insulated, but each day that the temperature drops below 25°F either 200 gallons per inch of diameter should be flushed through each pipe or constant flows indicated in Table 11 can be maintained to prevent ice formation or accumulation.

To maintain the thermal conductivity of the pipe insulation within reasonable limits, it is necessary to use either protective coverings which exclude water or an insulation which does not absorb water. The two asphalt-impregnated protective coverings which were used in the cold chamber tests were found to be hard and somewhat brittle under low

temperature conditions. Under moderate temperatures and with great care in applying the coatings, they could be made water tight and the water tightness could be maintained under moderate impact; however, under cold temperatures and severe impact, it can be expected that the integrity of the coverings would not be maintained. Similarly, sheetmetal protective coverings, while not affected by temperature, will not maintain water-tight joints when subjected to severe impact.

Table 13. Recommended Combinations of Heating and Insulation for Pipe Protection in Regions III and IV

Nominal Pipe Size (in.)	Region III		Region IV	
	Insulation Thickness (in.)	Daily Water Flushing if Temperature is Less Than 15°F (gal/ft)	Insulation Thickness (in.)	Daily Water Flushing if Temperature is Less Than 25°F (gal/ft)
2	1	1	1	1/2
3	1	1	1	1/2
4	1	1	1-1/2	0
6	1-1/2	0	1	0
8	1	0	1	0
10	1	0	1	0
12	1	0	1	0

As water tightness cannot be maintained under the conditions to which the pipes are subjected, use of a nonabsorbent insulation is indicated. With nonabsorbent insulation, the protection afforded by the lowest cost protective covering is adequate.

Cement—asbestos pipe with polyurethane insulation and cement—asbestos outer protective covering was found to be adequately protected from the effects of weather and wave action. However, the following deficiencies and difficulties are considered to make it unsuitable for under-pier service.

1. The heating element must be internal. The special fittings required to introduce the internal element plus the installation and maintenance of the element increase the cost prohibitively.

2. Additional supports for the heavy cement—asbestos pipe plus special supports to take the lateral thrust also increase the costs and the difficulty of installation.

3. Temperature control is poor with the internal heater.

The heating elements most easily installed were strip heaters which could be taped to the pipe. Good thermal contact was obtained from the taping plus the compression by the insulation. No cement is necessary and the insulation can be installed on the pipe without modification. Two of the strip heating elements as well as the mineral-insulated cable were custom made. Although fabrication in the field may be possible, making good joints in these elements is difficult and is not recommended. The conducting mineral film tape costs less than the other strip heaters, although more than the mineral-insulated cable. It is easily cut to length in the field and, therefore, can be fit between the flanges of the pipe as installed. Nylon-insulated wire can connect the heating elements across flanges.

CONCLUSIONS

1. Where heating systems are required for freeze protection, electric heating elements attached directly to the outside of the pipe are preferred.

2. The heating capabilities of the heating elements tested were equal, therefore the selection of heaters should be based on cost and ease of installation.

3. Strip heaters which can be taped to the pipe without the use of cement are easiest to install.

4. If heating elements must be fabricated in the field, the conducting mineral film tape, which was the least expensive of the strip heaters tested, is more satisfactory than custom-made heating elements.

5. Cement—asbestos pipe can adequately protect pipe insulation against the effects of weather and wave action, but the complication of internal installation of the heating elements plus the heavy weight and need for extra lateral supports make cement—asbestos pipe unsuitable for freeze protection use.

6. A nonbrittle, nonabsorbing insulation installed with the lowest cost protective coating is adequate for most installations.

RECOMMENDATIONS

1. Pipes under piers installed north of, but not including Philadelphia, Pennsylvania, on the East Coast and Seattle, Washington, on the West Coast should be installed with conductive mineral film electric heating elements,

polyurethane foam insulation, and asphalt-impregnated felt and asphaltic mastic protective covering. Pipes under piers in Northern inland and Great Lakes areas should be similarly protected.

2. Pipes under piers installed between and including Philadelphia, Pennsylvania, and Norfolk, Virginia, on the East Coast and Seattle, Washington, and Portland, Oregon, on the West Coast should be installed with polyurethane foam insulation and asphalt-impregnated felt and asphaltic mastic protective covering. Insulated pipes 4 inches in diameter (IPS) and under must be flushed with 250 gallons of water per day whenever the temperature drops to or below 20°F. This is adequate for 600 feet of pipe under 9 days of the worst conditions and would be adequate for 1,000 feet of pipe for 5 days of the worst conditions.

3. Pipes under piers installed south of Norfolk, Virginia, on the East Coast and Portland, Oregon, on the West Coast need not be insulated. Whenever the temperature falls below 25°F, a total volume of water equal to 200 gallons multiplied by the nominal pipe size should be flushed through the pipes.

4. On pipes requiring heating elements, the elements should be cut to fit between the flanges, and connections across the flanges should be made with special nylon insulated wire or mineral insulated cable; two thermostatic control elements should be installed, one at the extreme end of the pipe and one at the midpoint of the pipe and wired so that either element, sensing a temperature of 35°F, will actuate the heating circuit. The thermostatic bulb should be secured to the outer surface of the heating element before the insulation is applied.

Appendix A

COLD CHAMBER TESTS

INTRODUCTION

Four pipe sections were assembled to evaluate the following variables: (1) one kind of insulation (polyurethane), (2) two different pipe materials (cement—asbestos, steel), (3) three different types of protective coverings (cement—asbestos, laminated asphalt-impregnated fiberglass, foil, and asphaltic mastic, and asphalt-impregnated felt and asphaltic mastic), and (4) four different types of electric heating devices (MIC cable, conductive mineral film element, rubber-protected wire mesh element, and silicone-rubber-protected element). Figures A-1 and A-2 show the arrangement of the test pipes in the cold chamber.

Information on pipe materials, insulation, protective coverings, and heating elements is contained in Table A-1.

The air temperature in the cold chamber was held at 30°F, 15°F, 0°F, and -15°F for extended periods. The various heating elements cycled on and off in response to the thermostats and maintained the water within the pipes above 32°F.

OBSERVATIONS

The protective coverings with asphalt-impregnated material and asphaltic mastic became hard at low temperatures. The asphalt-impregnated felt and asphaltic mastic coatings were judged to be more brittle than the Pittwrap. The cement—asbestos protective covering was not obviously affected by the low temperature.

The pipe with the internal heating element and the thermostat bulb was subject to long on-off cycles of the heating element and wide ranges of water temperature because the water temperature activated the thermostat. The pipe with the thermostat bulb on the pipe but away from the heating element had somewhat longer cycles than the two which had the thermostat bulb touching the heating element.

No significant differences were measured in the heat losses from pipes B, C, and D. This is to be expected as the differences in the insulating effects of the protective coverings are small when combined with the insulating effect of the polyurethane insulation. Pipe A had higher heat losses as this pipe was larger in diameter, and the thickness of the polyurethane was less.

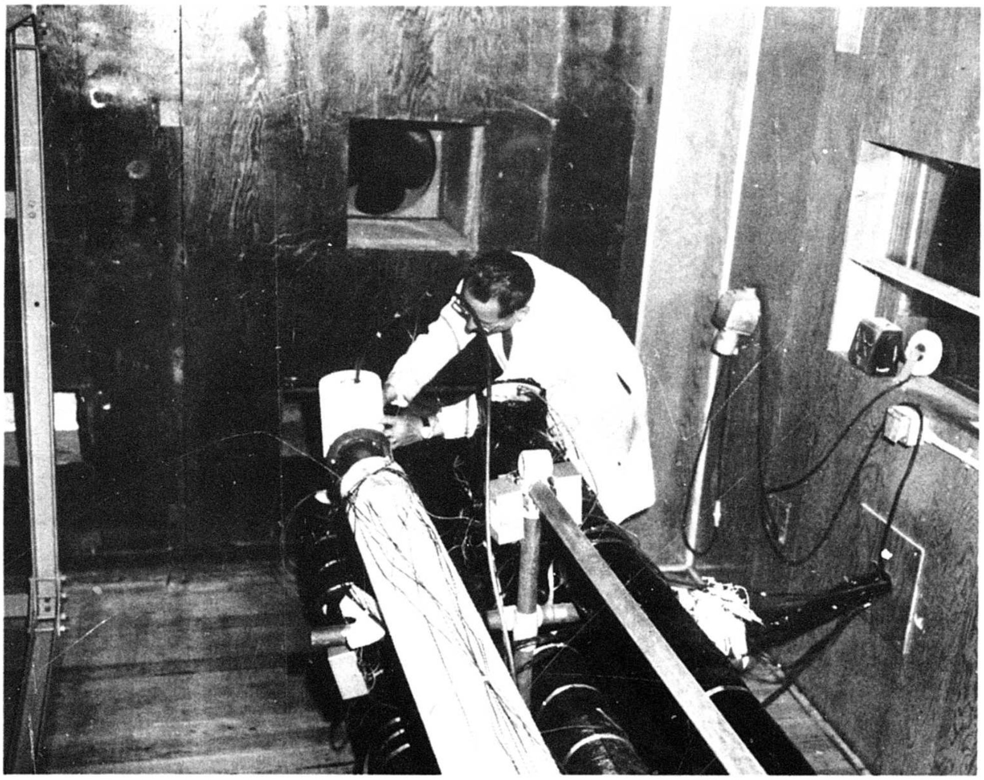

Figure A-1. Insulating filling tube and heating cable access of cement—asbestos test pipe.

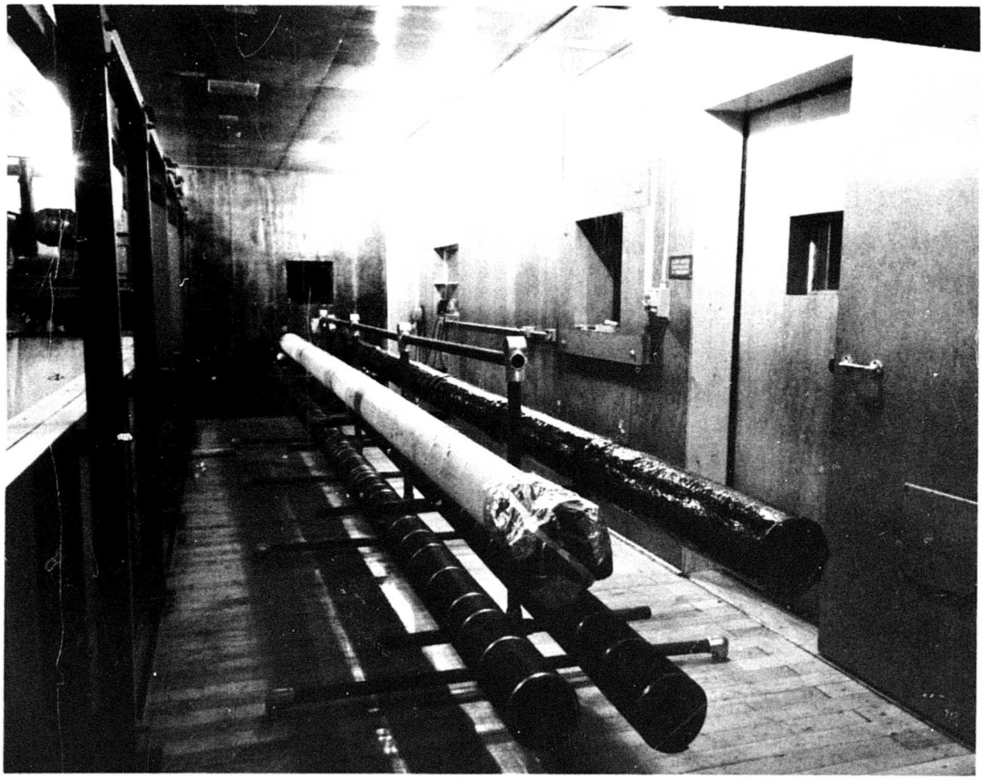

Figure A-2. Arrangement of test pipes for cold chamber tests.

Table A-1. Pipe Materials, Insulation, Protective Coverings, and Heating Elements Used in Cold Chamber Tests

Pipe Section	Nominal Pipe Size (in.)	Pipe Material	Insulation	Protective Covering	Heating Element	Location of Heating Element	Location of Thermostat
A	3	cement–asbestos	polyurethane	cement–asbestos	MIC cable	in pipe	in pipe
B	2	steel	polyurethane	Pittwrap1/	Electro-wrap2/	on outside of pipe	on heating element
C	2	steel	polyurethane	asphalt-impregnated felt and asphaltic mastic	Electro-mesh3/	on outside of pipe	on pipe touching heating element
D	2	steel	polyurethane	asphalt-impregnated felt and asphaltic mastic	Hot Foil4/	on outside of pipe	o.. pipe 1 inch from heating element

1/ Pittwrap is the trade name for a laminated asphalt-impregnated fiberglass, foil, and asphaltic mastic protective covering.
2/ Electro-wrap is the trade name for a conductive mineral film heating element.
3/ Electro-mesh is the trade name for a wire mesh heating element with a rubber protective covering.
4/ Hot Foil is the trade name for a silicone-rubber-protected heating element.

The thermostats operated with an on-off cycle regardless of the temperature setting of the thermostat. Under worst conditions, best performance was obtained with equal off and on periods.

The cement—asbestos pipe was heavy. It required multiple supports to maintain alignment (ordinarily this type of pipe is placed in a trench and is uniformly supported), and if it were under pressure, it would have required blocking at the pipe ends to avoid the joints opening because of the end reaction. The heating unit for the asbestos—cement pipe must be inserted in the pipe. This arrangement imposes problems in leading the element into the pipe, in controlling the temperature of the water, and in avoiding undue temperature variations within the pipe.

Appendix B

WINTER WEATHER DATA FOR REPRESENTATIVE NAVAL STATIONS

Information for 17 different coastal cities obtained from References 8 and 9 is tabulated in Table B-1.

Table B-1. Weather Data for Selected U. S. Cities

(All temperatures in °F)

City	Average 1/ January Temperature	Extreme Minimum Temperature	Median Annual Extremes	97.5% Temperature 2/	January Degree Days
Portland, Me.	20.5	-39	-14	0	1,373
Juneau, Alaska	26	-21	-11	-4	1,203
Portsmouth, N. H. 3/	24.5	-30	-8	3	1,250
Providence, R. I.	29	-9	0	10	1,125
Boston, Mass.	29	-12	-1	10	1,113
Newport, R. I.	4/	4/	1	11	4/
New York, N. Y.	33	-14	7	16	995
Kodiak, Alaska	4/	4/	4	12	4/
Baltimore, Md.	34	-4	8	15	955
Philadelphia, Pa.	33	1	7	15	986
Washington, D. C.	36	1	6	15	893
Seattle, Wash.	37	0	14	24	862
Portland, Ore.	39.5	3	17	24	791
Norfolk, Va.	41.5	11	18	23	729
San Francisco, Calif.	50	30	32	37	462
Charleston, S. C.	50	14	19	27	472
Jacksonville, Fla.	54	17	26	32	331

1/ Average January temperature is obtained from 65°F -(January Degree Days/31).

2/ The 97.5% temperature is the level which is exceeded 97.5% of the total hours in December, January, and February.

3/ Portsmouth average January temperature and extreme minimum and January degree days were estimated from comparison of data for Boston, Mass.; Concord, N. H.; and Portland, Me.

4/ Not available.

These cities appear to be separable into five distinct regions (Figure 1) which exhibit similar temperature conditions, although it is readily seen that variations in average temperatures, extreme minimums, and the 97.5% temperatures are not always uniform nor consistent. These five regions are:

Region I. "Severe"—Portland, Maine; Juneau, Alaska; and Portsmouth, New Hampshire. (Also inland and Great Lakes locations).

Region II. "Cold"—Boston, Massachusetts; Providence, Rhode Island; Newport, Rhode Island; Kodiak, Alaska; and New York, New York. (New York is a borderline situation with its average winter temperature corresponding to the "moderate" group, but its extreme minimum corresponding to the "cold" group.)

Region III. "Moderate"—Baltimore, Maryland; Philadelphia, Pennsylvania; and Washington, D. C.

Region IV. "Mild"—Seattle, Washington; Portland, Oregon; and Norfolk, Virginia.

Region V. "Very Mild"—San Francisco, California; Charleston, South Carolina; and Jacksonville, Florida.

REGION I

The January total of 1,275 degree days gives an average January temperature for this region of 65 - (1,275/31) = 23.9°F. If in January, 10 days averaged the 97.5% value (0°F) and 2 days averaged between the 97.5% value and the extreme minimum (-15°F)—i. e., a combined total of 810 degree days—the balance of the month would average only 40.5°F to obtain 1,275 degree days. It appears plausible that the January temperature may seldom exceed 32°F and therefore provide no relief from freezing in the pipes. The design of freeze protection systems, therefore, should be based on an extended period of 0°F weather.

The assumed design weather conditions are for a continuous period of 0°F with 54 hours at -15°F.

REGION II

For 1,125 degree days in January, the average January temperature for this region is 65 - (1,125/31) = 28.7°F. With 10 days at 10°F and 2 days at -2°F (a total of 684 degree days), the balance of the month would average 41.8°F. In this case, the design of the freeze protection system should be based on an extended period of 10°F weather.

The assumed design weather conditions are a continuous period of 10°F plus 54 hours at -2°F.

REGION III

The average January temperature for this region based on 950 degree days is 65 - (950/31) = 34.3°F, so it appears that at least half the time the temperatures would be above freezing. If it is assumed that 50% of the January degree days occur during a period of cold weather, and that all the coldest days of the winter occurred at this time, then 2-1/4 days at 8°F (128 degree days) and 6-3/4 days at 15°F (338 degree days) would mean about 9 days of extreme cold (466 degree days). The other 22 days would have an average temperature of about 43°F. The freeze protection system, therefore, should be such that not more than 50% of the water in the pipes will freeze if subjected to an ambient temperature of 15°F for 162 hours plus 8°F for 54 hours.

REGION IV

The average January temperature for this region based on 750 degree days is 65 - (750/31) = 40.8°F. If it is assumed that 50% of the degree days occur during a period of extreme cold and that all the coldest days of the winter occurred at this time, 2-1/4 days at 13°F (117 degree days) and 6-3/4 days at 24°F (276 degree days) would result in 9 cold days accounting for 393 degree days with the other 22 days averaging 48.8°F. The freeze protection system, therefore, should be such that not more than 50% of the water in the pipes will freeze if subjected to an ambient temperature of 24°F for 162 hours plus 13°F for 54 hours.

REGION V

The average temperatures in this region are above freezing and it would be expected that 25°F temperatures would not continue for more than a few hours in the extreme case. A bare 4-inch pipe without insulation or any outer covering would be 23% frozen if an average temperature of 25°F were maintained for 10 hours.

DESIGN TEMPERATURES

The design temperatures presented in Table B-2 have been selected for the five regions:

Table B-2. Design Temperatures for Systems to Protect Piping Under Piers Against Freezing

(All values in ^{o}F)

Region	Average January Temperature	Extreme Minimum Temperature	Median Annual Extremes	97.5% Temperature	Average of 97.5% Temperature and Extreme Minimum	January Degree Days
I	24	-30	-11	0	-15	1,275
II	29	-14	1	10	-2	1,125
III	34.5	1	7	15	8	950
IV	34.5	3	16	24	13	750
V	50.5	17	21	32	25	450

Appendix C

FACTORS AFFECTING HEAT LOSS FROM PIPES

As discussed in the text, the heat loss from pipes, under steady-state conditions, will depend upon:

(1) Coefficient of heat transfer between outer surface and air

(2) Thermal conductivity and thickness of the piping, insulating materials, and ice if present

(3) Coefficient of heat transfer between water and pipe inner surface

The heat lost to air may be determined from the following equations:

$$Q = U_o A_o \Delta t \qquad \text{(C-1)}$$

Δt is the temperature difference between water in pipe and ambient air. When there is a flow of water in the pipe with a consequent change in water temperature, Δt_m, the log mean temperature difference is used in Equation C-1.

$$\frac{1}{U_o} = \frac{1}{h_o} + \frac{1}{C_1} + \frac{D_o \ln\left(\frac{D_1}{D_2}\right)}{2k_2} + \frac{D_o \ln\left(\frac{D_2}{D_3}\right)}{2k_3} + \frac{D_o \ln\left(\frac{D_3}{D_4}\right)}{2k_4} + \frac{D_o}{h_1 D_4} \qquad \text{(C-2)}$$

The values selected for these factors in the design of the piping systems and their relative importance are discussed below.

AIR FILM

The value of 6 Btu/(hr)(ft^2)(^oF) is widely accepted for the heat transfer coefficient for a nonreflective surface exposed to 15-mph winds in winter.[10] Because of the air turbulence expected under the piers, it is assumed that the entire pipe surface will have the above coefficient of heat transfer.

WATER FILM

The heat transfer coefficient between the water and the pipe wall, h_1, was determined using the following equations. For forced convection under turbulent conditions,

$$\frac{h_1 D_3}{k_3} = 0.023 \left(\frac{G D_3}{\mu} \right)^{0.8} \left(\frac{c_p \mu}{k_3} \right) \quad \text{(C-3)}$$

and, for forced convection under laminar conditions,

$$\frac{h_1 D_3}{k_3} = 1.62 \left[\left(\frac{G D_3 c_p}{k_3} \right) \left(\frac{D_3}{L} \right) \right]^{1/3} \quad \text{(C-4)}$$

For a 3-inch (IPS) pipe with water at 32°F, turbulent conditions **($N_{RE} > 2{,}000$)** are present when a flow rate of 4 gpm is exceeded. The coefficient of heat transfer, h_1, at this flow rate is calculated from Equation C-3 to be 38 Btu/(hr)(ft^2)(°F). At 10 gpm, h_1 increases to 80 Btu/(hr)(ft^2)(°F).

For laminar conditions **($N_{RE} < 2{,}000$)**, Equation C-4 applies. In the 3-inch pipe at 2.85 gpm **($N_{RE} = 1{,}500$)**, h_1 is calculated to be 16.7 Btu/(hr)(ft^2)(°F); at 0.01 gpm (almost stagnant conditions), h_1 is found to be 2.54 Btu/(hr)(ft^2)(°F).

For this study, based on the calculations above, the following values of h_1 were assumed:

Stagnant condition: h_1 = 4 Btu/(hr)(ft^2)(°F)

Laminar flow **($N_{RE} < 2{,}000$)**: h_1 = 20 Btu/(hr)(ft^2)(°F)

Turbulent flow **($N_{RE} > 2{,}000$)**: h_1 = 40 Btu/(hr)(ft^2)(°F)

EFFECT OF ICE ON INSIDE SURFACE

The thermal conductivity of ice is relatively high (k_4 = 1.26 Btu/(hr)(ft^2)(°F/ft)).[1] Once ice has started to form, the surface area of the water–ice interface decreases progressively. The insulating effect of ice is negligible for insulated pipes, but it may be significant for uninsulated pipes.

PIPE WALL

The conductivity of steel pipe walls is high (k = 26.2 Btu/(hr)(ft^2)(^{o}F/ft).[1] Since the thicknesses of the pipe walls are small, the conductances are very high. Conductance for 0.33-inch-thick pipe walls (wall thickness will vary from 0.213 inch to 0.375 inch depending on pipe size) is about 1,050 Btu/(hr)(ft^2)(^{o}F). This high value causes negligible change in the overall coefficient of heat transfer, U_o, and may be omitted for all practical purposes.

THERMAL INSULATION

All calculations have been made for polyurethane insulation with k = 0.014 Btu/(hr)(ft^2)(^{o}F/ft).[5] Because the area varies with insulation thickness, the logarithmic mean area is used. If any insulation other than polyurethane is used, the thermal resistance must be calculated using the conductivity of the substitute insulation.

OUTSIDE PROTECTIVE COVERING

The most common outside protective covering is an asphalt-impregnated fiber sealed with an asphaltic sealant. This covering protects against moisture and physical damage and is not selected for its insulating qualities. In general, two layers of 30-pound asphalt-impregnated paper or the equivalent are used. The conductance of two layers of mopped 15-pound felt is 8.35 Btu/(hr)(ft^2)(^{o}F);[10] for two layers of 30-pound felt, a conductance of 4.1 Btu/(hr)(ft^2)(^{o}F) is assumed. Other protective coverings of similar weights are assumed to have about equal conductances. The effect of these various factors were evaluated, and a comparison showed:

1. The effect of pipe wall may be neglected all cases.
2. If the ambient air is below 32^{o}F and water is stagnant in the pipe, the freezing of water will depend entirely upon the duration of the below-freezing temperatures.
3. If the ambient air is below 32^{o}F and water is flowing through the pipe, the length of the exposed pipe and flow rate would determine the condition of water in the pipe. Flow rates must be maintained so that the water temperature is above 32^{o}F in the pipe.
4. Insulation on the pipe decreases the minimum flow rate necessary to prevent freezing.

LIST OF SYMBOLS

A_o Area of outer surface, ft^2

c_p Specific heat at constant pressure of water, Btu/(lb)(^oF)

C_1 Conductance of protective covering, Btu/(hr)(^oF)

D_o Diameter of outer surface, ft

D_1 Diameter of protective covering ($\approx D_o$), ft; also outer diameter of insulation

D_2 Inner diameter of insulation, ft; also outer diameter of pipe

D_3 Inner diameter of pipe, ft; also outer diameter of ice, if formed

D_4 Inner diameter of ice, if formed, ft

G Mass velocity, lb/(sec)(ft^2)

h_o Coefficient of heat transfer between air and outer surface, Btu/(hr)(ft^2)(^oF)

h_1 Coefficient of heat transfer between water and inner surface, Btu/(hr)(ft^2)(^oF)

k Thermal conductivity, Btu/(hr)(ft^2)(^oF/ft)

k_2 Thermal conductivity of insulation, Btu/(hr)(ft^2)(^oF/ft)

k_3 Thermal conductivity of pipe wall, Btu/(hr)(ft^2)(^oF/ft)

k_4 Thermal conductivity of ice, Btu/(hr)(ft^2)(^oF/ft)

L Length of pipe, ft

N_{RE} Reynolds number, dimensionless

Q Heat transferred from pipe to air, Btu/(hr)

Δt Temperature difference between ambient air and water in pipe (no flow), ^oF

Δt_m Log mean temperature difference between ambient air and water in pipe (with flow), ^oF

U_o Overall coefficient of heat transfer based on outside diameter, Btu/(hr)(ft^2)(^oF)

μ Absolute viscosity of water, lb/(hr)(ft)

ρ Density, lb/ft^3

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13. ABSTRACT

Pipes carrying freshwater or sewage are often exposed to severe weather conditions under piers and therefore must be protected from freezing. The Naval Civil Engineering Laboratory has studied the problems associated with freeze protection of piping systems, reviewed weather data for U.S. coastal cities having temperatures comparable to those of nearby Navy installations, conducted cold chamber tests on several freeze-protection systems, and developed freeze-protection criteria for exposed piping systems. Results of these studies indicate that freeze protection can best be obtained with conducting mineral electric heating elements insulated with polyurethane foam and protected with a covering of asphalt-impregnated felt coated with asphaltic mastic. In the colder regions, heaters, insulation, and protective covering are required; in regions of moderate winter cold only insulation and protective covering are required; and in regions having very mild winters, no insulation, protective covering, or heaters are required.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Freeze protection						
Exposed pipes						
Insulation						
Electric heating elements						
External elements						
Internal elements						
Steam tracers						
Direct resistance heating						
Heated enclosures						